GLACIAL STUDIES IN GREENLAND. VI.

THE REDCLIFF PENINSULA.—*Continued.*

The Bryant glacier.—In a valley about three miles east of the Fan glacier there lies another tongue of the peninsular ice-cap to which the name Bryant glacier has been applied. Like the Fan glacier it is but a short lobe protruding from the ice mantle of Redcliff peninsula on its southerly side. It descends an open valley less than a mile in width, and by estimate less than three miles long. Its course is direct and its slope somewhat greater than that of the Fan glacier, as will be seen from the photographic illustrations, Figs. 31 and 32.

The most striking characteristic of this glacier is the verticality of its face. In this particular it introduces us to the prevailing northern type. Attention has heretofore been called to the curved profile of the terminal slope of the glaciers of Disco Island, and of southern latitudes generally. The Igloodahomyne glacier which we first visited in the northern latitudes does not very widely depart from these. The Fan glacier approaches verticality in its lower face, but its brow is so much curved and the cones and snow embankments along its face covered so much of the vertical part of its front that it falls short of a typical expression of the northern habit. In the Bryant glacier, however, verticality of face reaches a full and characteristic expression. Not only is the face vertical but it is disposed to overhang so that from time to time the upper portion breaks away and falls to the base. This disposition to overhang is doubtless to be attributed partly to the more rapid movement of the upper layers of ice and partly to the more rapid melting of the discolored ice below, the two agencies acting jointly. The verticality is not only a characteristic of the end of the glacier but of the sides. This seems less strange, however, for here we might find a plausible explanation in the undermining of the streams

that run alongside the glacier and constitute its main drainage system, and in the reflection and radiation of heat from the adjoining cliffs. But neither of these afford an explanation of the abruptness of the end of the glacier. This terminates upon a flat gravel plain produced by the glacial wash, and no cliff lies in front between it and the Gulf, a mile or two distant. As this glacier has a southern frontage, the phenomenon might perhaps at first thought appear to be due to exceptional exposure to the southerly sun, but the sun is less partial in its favors here than in southern latitudes. During the main melting season it is constantly circling above the horizon and throwing its rays on all sides of the glacier, and, although the southerly sun is more effective than any other, the difference is less than in lower latitudes. Besides, we shall find in the study of other glaciers of the region that eastern and western and even northern exposures present the same characteristics. The explanation seems to lie in the low inclination of the sun's rays and in their impact from all points of the compass in succession. It is obvious that rays of low slant strike the back of the glacier at a very acute angle and easily glance away with little effect. On the edge of the glacier, however, they strike more directly against the surface and hence have greater effect. In addition to this, the slanting rays that impinge on the surrounding surface at low angles are again reflected at like low angles, and hence a much larger proportion of them strike upon the edge of the ice. Thus it appears that a larger *proportion* of the sun's rays fall on the edges of a glacier in high latitudes than upon the edges of a glacier in low latitudes, and it is obvious that it is the *proportional* effect of the sun's rays that determines the contour. For like reasons there is a larger proportional reflection from prominences in the vicinity of the ice, so that, although verticality of face is not dependent on the presence of reflecting cliffs near the glaciers, it is facilitated by them. It will be found in subsequent observations that where promontories of rock rise through the ice-sheet, forming the "nunataks" of the Greenlanders, the ice, in many instances, does not crowd against their sides but is

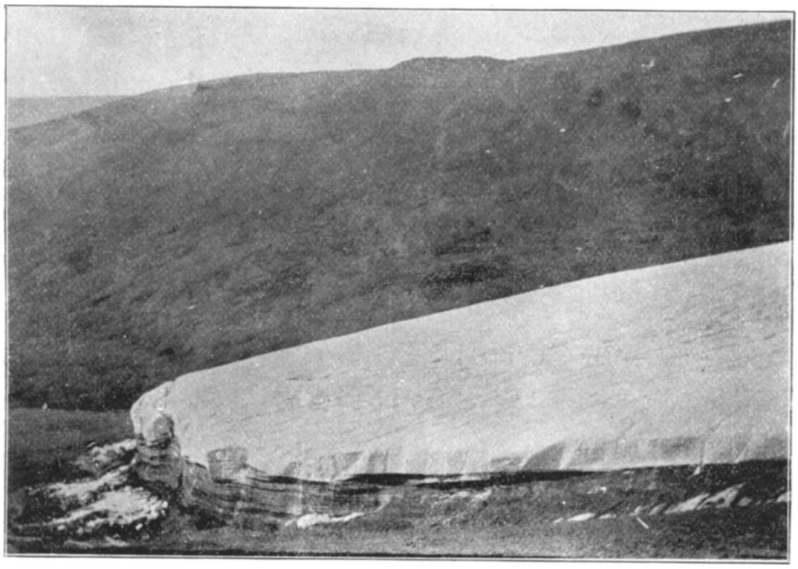

FIG. 31.—Terminal portion of Bryant glacier seen from the east, showing clean, white ice above and stratified, discolored ice below, with a talus slope at the base. Height of vertical face above the gravel plain in front about 140 feet. In this and the following views the amount of débris in the discolored ice is greatly exaggerated by surface spreading.

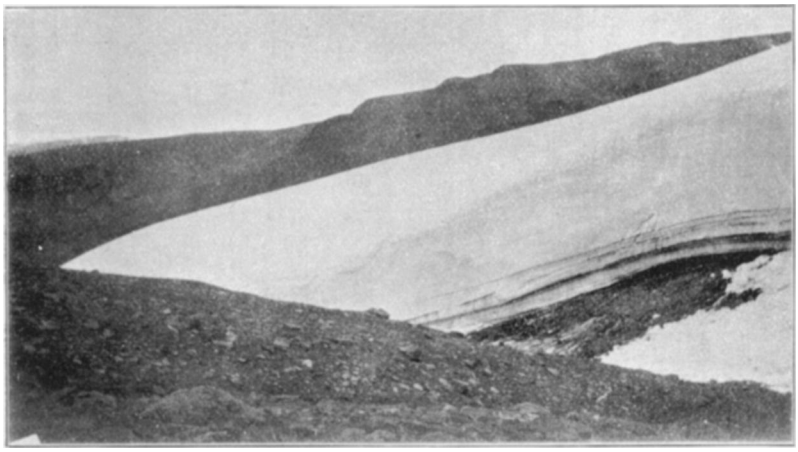

FIG. 32.—Middle portion of Bryant glacier seen from the east, showing increased thickness of white ice above and the curvature of the discolored layers below.

melted back, leaving a moat-like ditch between the eminence and the mass of the glacier surrounding it, not unlike the defensive trench of an ancient castle. Whenever the motion of the ice is considerable, however, this intervening space is absent and the ice impinges forcibly upon the base of the prominence.

So striking a feature could not well escape the notice of previous visitors to the region. In the Greeley reports the designation "Chinese Wall" is aptly applied to it. Its significance and especially the internal structure and mode of action which it reveals were not unnaturally overlooked amid the engrossing demands of other interests.

Stratification.—This melting back of the edge of the ice, developing a vertical face in the place of the usual slope, is a matter of the utmost good fortune to the glacial student, as it displays the basal organization of the ice and reveals its methods of work to a degree that could scarcely have been anticipated. It is as though a Titan with the blade of a giant knife, one or two hundred feet long, had sliced away the border of the glacier, giving us a vertical section across the end and along both sides. This truncation of the edge reveals a remarkable stratification of the ice and an equally remarkable insetting of rock débris. The stratification of glaciers is by no means an unknown phenomenon, but I doubt whether it had ever been suspected that it reaches an extent and an intimacy such as is here displayed. As will be readily seen from the accompanying photographic illustrations, the ice is not only arranged in layers, but these are subdivided in a very intimate fashion, so intimate indeed in many portions as to pass beyond simple stratification in its usual sense and become lamination. In extreme instances the thin layers number as many as twenty to the inch. By turning to the illustrations (Figs. 31, 33 and 35, in particular) it will be seen that there is a thick stratum of clean, white ice at the top, beneath which there is a zone of ice darkened with much débris, and at the bottom a talus slope formed from a mixture of ice and rock fallen from above, commingled with the residue of snow drifts. The talus slope rises to heights of thirty and forty feet, and occasionally more.

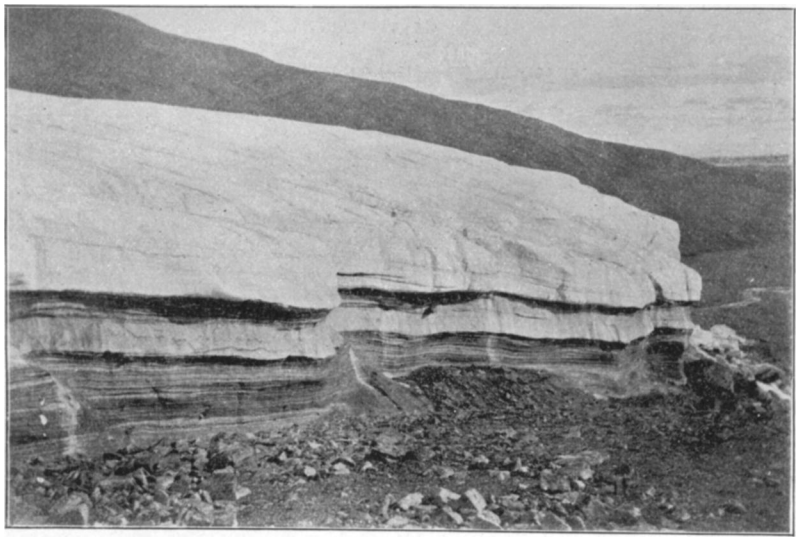

FIG. 33.—Terminal portion of Bryant glacier seen from the west, showing the stratification and lamination of the ice and the talus slope below. Inglefield gulf seen in the distance at the right.

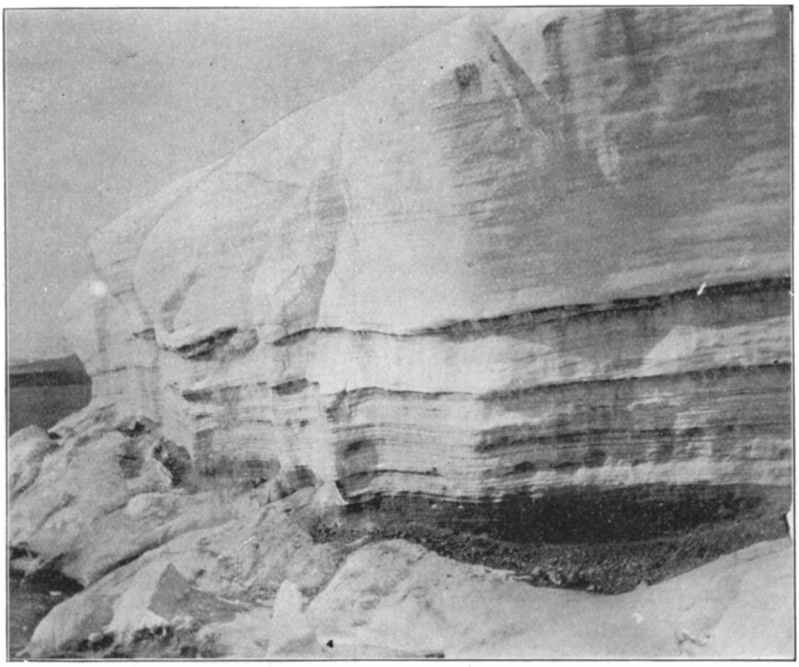

FIG. 34.—Portion of the "Chinese Wall" showing distinctly the stratification of the white ice as well as the discolored portion. It illustrates also the arrangement of the rock débris in definite planes.

The discolored ice above this measures fifty or sixty or even seventy feet, while the white ice above is forty or fifty feet thick at the edge, and rapidly increases backwards. Measurements made with a binocular Locke level by sighting across the extreme front of the glacier from the adjacent slope showed that the discolored ice rose ninety-five feet above the gravel plain in

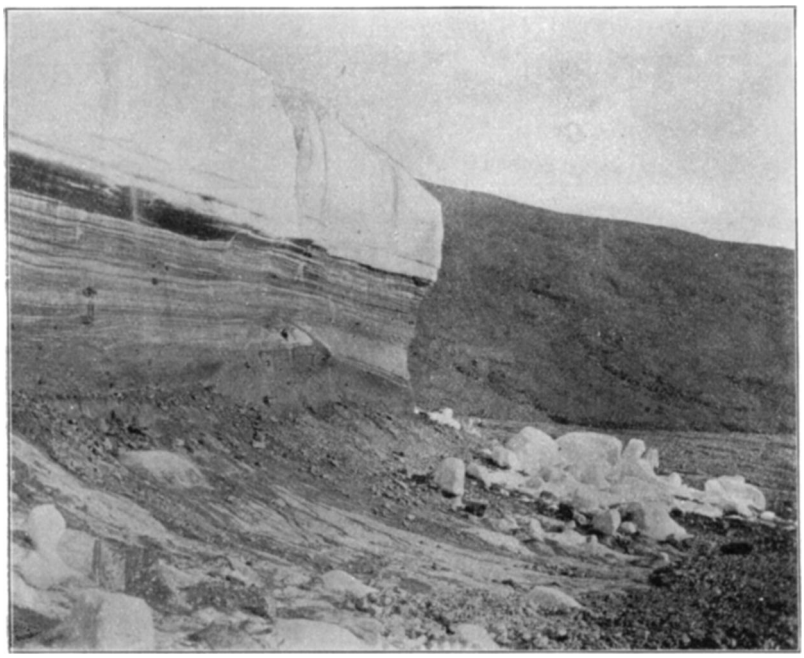

FIG. 35.—A nearer view of a portion of the front of the Bryant glacier near the middle of the valley, showing the verticality of the face, the stratification of the ice, the insetting of the bowlders, the formation of the talus, and the smoothness of the valley bottom.

front, while the white ice rose forty-five feet above this, making the total vertical height of the extreme front 140 feet.

The stratification is not confined to the discolored portion, although it is only obscurely expressed in the white ice. Nor is the stratification of the two parts identical. Perhaps it may be appropriately said that there are two classes of stratifi-

cation. The one predominates in the white ice and the other in the discolored. The first consists of an alternation of layers of porous, opaque, white ice with layers of compact, transparent, blue ice. The blue layers are thin, while the

FIG. 36.—Nearer view of the middle of the front wall of the Bryant glacier, showing details of stratification and the trench cut in the face of the glacier and of the talus slope by a small stream descending from the surface of the glacier.

white layers are relatively thick. This form of stratification extends into the discolored portion, but the distinctive stratification of this portion consists of the introduction of layers of rock débris between sheets of ice. In general this débris was found

to be confined to very definite planes. In some places there was a somewhat promiscuous scattering of the rock material through the ice, and in exceptional cases considerable thicknesses of ice were freely inset with foreign matter, but as a rule the erratic material was distributed in extremely thin sheets between layers of ice that remained essentially pure. The typical section was therefore made up of layers of pure, clean ice separated by films of rocky débris. The rocky material varied in size from the finest silt up through pebbles and fragments of various sizes to bowlders or blocks of rock several feet in diameter. There was no special assortment of this material. Between the same two layers of ice might be found, here an attenuated film of fine silt,

FIG. 37.—Diagrams illustrating the behavior of the laminæ of the ice in passing embedded bowlders.

a little farther on a layer of sand, or a pebble, or a chip of rock, or all these together, while now and then a bowlder or massive block might be encountered. It was observed that usually these larger pieces centered upon the plane of débris, a portion of their mass rising above it and a portion sinking below it. Where the ice was closely laminated the larger fragments necessarily extended across the horizon of several laminæ, and it was interesting to observe that in many of these cases the laminæ divided, a part bending up and passing over the rock fragment and a part bending down and passing under. In cases where the mass was large, some of the central laminations ended abruptly against the mass and new laminations appeared on the opposite side, while the laminæ above and below were bent around the mass as illustrated in Fig. 37. I observed no cases in which the mass seemed to have descended through the ice, as though carried down by its superior gravity. In such a case it would be presumed to bend the laminæ down with it, or break across them. It appeared,

on the contrary, that the larger masses of rock equally with the smaller remained fixed.

The material embraced in the ice was found to consist in large part of indurated quartzose sandstone of a light pinkish-gray color. This appeared to be the sandstone previously described as constituting the second member of the clastic series. It comes out to the surface on the eastern side of the peninsula, forming the very picturesque cliffs of Karnah, and may be conveniently known as the Karnah sandstone. Besides this, there was some reddish sandstone and shaly débris belonging to the other members of the clastic series. There was also present a notable ingredient of crystalline rock, chiefly of the gneissic and granitic types. This constituted a decidedly subordinate percentage of the whole, but it was rendered conspicuous by its nature and is significant in that it indicates the existence of the gneissic series underneath the ice-cap somewhere between this glacier and the center of the peninsula, and it will be recalled that the peninsula is only about fifteen miles across.

By reference to the illustrations it will be seen that the number of layers of débris in the lower part of the Bryant glacier is very large. It is important to observe, however, that the amount of débris appears very much greater than it actually is because of the spreading of the silt over the face of the ice when it was freed by melting. Fig. 38 shows a portion whose layers were upturned at the foot of the glacier. The surface wash was cut away from a belt across the layers and a comparison of this with the rest will show the deceptiveness of the dirty surface. In a similar way natural surfaces that have been washed by streamlets from the surface of the glacier show the true content of débris.

The laminations that bear the débris are not usually continuous for very great distances. The first impression, perhaps, made on viewing the wall of discolored ice is that the more pronounced layers are continuous across its whole breadth, but upon closer inspection it will be seen that the layers thin out and disappear and others are introduced to take their places; even the broader bands are limited in their extent. None of them save,

perhaps, the twofold division, appear to pass from side to side of the glacier. This may be verified by comparing the east, the frontal and the west sides as shown in Figs. 31, 35 and 33.

The laminæ are generally plane or slightly undulatory and essentially horizontal, but occasionally they are warped and crumpled; sometimes they are faulted.

The major planes of stratification seem to be essentially parallel with the bottom of the glacier. In detail this is not always true, and theoretically it is probably not accurately true as a generalization—but in a broad sense it appears that the attitude of the layers is controlled by the bottom and not by the top of the glacier. The profile views illustrate this. Apparently the white ice thickens rapidly as we go back from the edge, while the discolored ice at the base probably remains approximately constant in thickness. This seems to me to agree with theoretical presumptions. The melting of the glacier is chiefly at the surface. There is little ground for believing that any considerable amount of interior melting takes place that is not compensated by refreezing. Hence the upper layer must thin out as it approaches the edge of the glacier, while the lower layers remain approximately constant. The ratio, therefore, of the débris-bearing ice to the white ice above it, as seen on the edge, cannot be regarded as applicable to the thicker portions of the glacier back from the edge. At the extreme margin of the Bryant glacier the débris-bearing ice constitutes two-thirds of the section. It certainly would lead us far astray to assume that the débris is distributed through two-thirds of the vertical section of the ice on the summit of Redcliff peninsula.

The drainage of Bryant glacier is essentially the same as that of the two northern glaciers previously described. The waters produced by melting are shed from the back of the glacier in rivulets, very few of which find an opportunity to descend to the bottom through crevasses because of the scantiness of these. The rivulets, however, instead of cascading down the sloping face of the glacier as they were permitted to do in the preceding instances, are forced to project themselves from the overhanging edge as

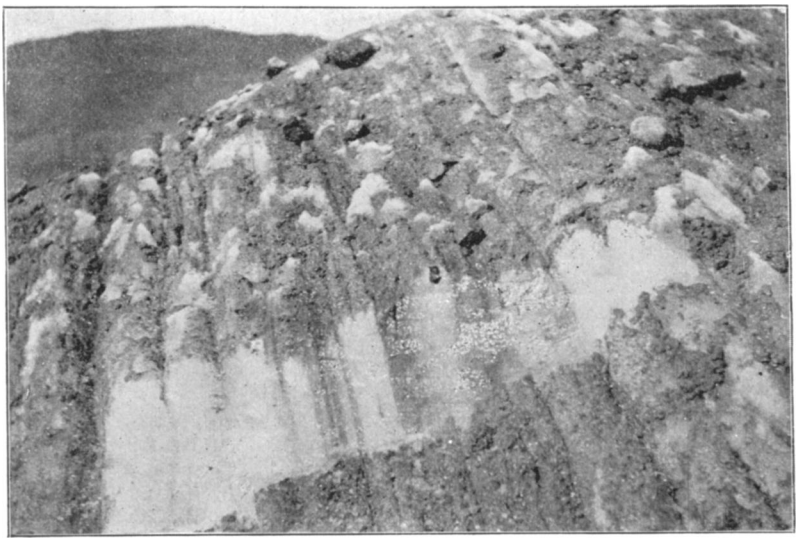

FIG. 38.—A nearer view of the débris-bearing layers which have been curved upwards to a nearly vertical position. From a portion of this the discolored surface has been cut away to show the difference between the real amount of débris included in the ice and the apparent amount deceptively indicated by the surface spreading. It also shows the definite arrangement of the internal débris in layers.

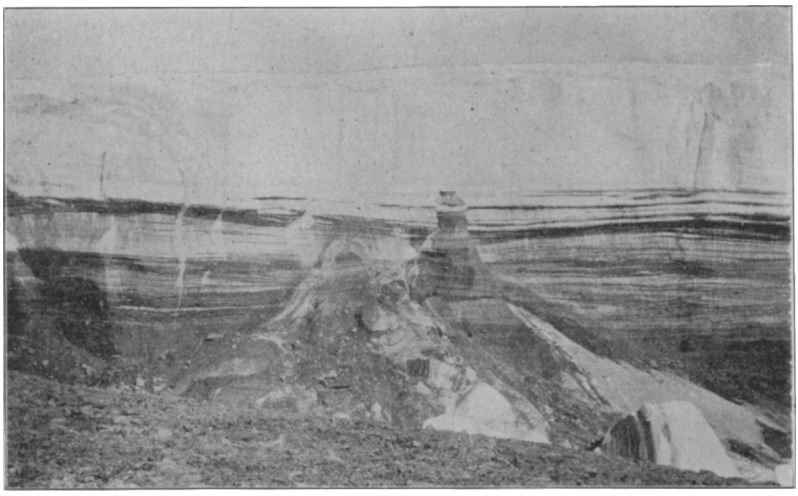

FIG. 39.—A portion of the front of Bryant glacier near the west side of the valley showing the inconstancy of the laminations and the formation of a monument of discolored ice off the face of the wall by the melting or falling away of the ice that once surrounded it.

free-falling little cataracts. Along the sides of the glacier these are gathered into a considerable lateral stream which occupies the trench between the glacier and the side of the valley. At the end of the glacier small streamlets flow away in large numbers but there is no central stream, nor any large central tunnel after the fashion of Alpine glaciers. The lateral streams are usually murky, but the frontal streams are essentially clear.

The plain in front of the glacier is produced by its own drainage and consists of bowlders, cobbles and coarse gravel, with some sand and silt. It spreads from bluff to bluff in a nearly uniform plane. There is no terminal moraine immediately in front of the glacier, unless the talus at its base be so regarded. Between its extremity and the sea, along the sides of the valley, there are some accumulations of erratic material that perhaps represent old moraines, but they scarcely have a distinctive character.

Ascent to the ice-cap.—On two occasions we ascended the plateau immediately east of Bryant glacier and went back to the edge of the ice-cap of the peninsula. At first the surface was found to be formed wholly of frost-riven fragments of the sandstone and shale series that constitute the uppermost member of the clastic terrane before described. Here and there an erratic bowlder was seen, but the amount of detectable drift on the surface was very small. At a height of about 1600 feet and at a point perhaps two miles back from the Gulf, moraine-like aggregations of rounded erratics were met. These did not form a sharply defined moraine with a definite outer border, but the transition from local débris was measurably abrupt. As the ascent was continued there was an increase in the amount of drift and the topography became more moraine-like, although it never passed beyond the milder type of morainic hills and hollows. The material was chiefly bowlders ranging from one to three or four feet in diameter. Cobbles and coarse gravel were present, but sandy and clayey constituents were scant. As the edge of the ice-cap was approached streamlets issuing from the border of the ice were encountered and became increasingly frequent. They

had brought down with them gravel and sand and by spreading these out had smoothed the surface in a notable degree. Streamlets were abundant on the plateau surface even within short distances of the edge of the valley occupied by the Bryant glacier and seemed to quite ignore its existence. This seems to mean the same thing as the absence of a central stream under the

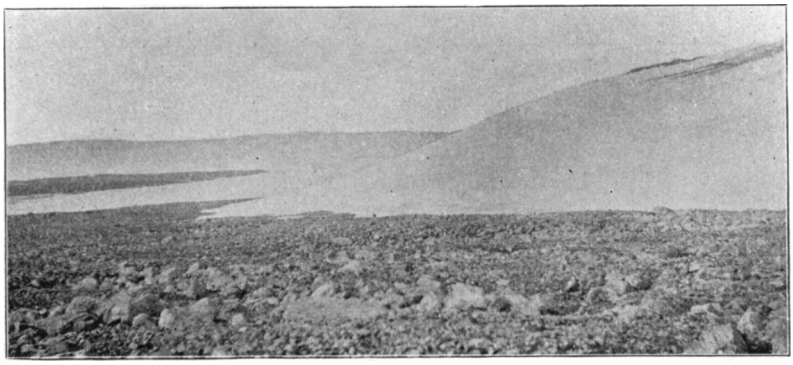

FIG. 40.—The southern edge of the ice-cap of the Redcliff peninsula a short distance east of the Bryant glacier (which is represented by the lowest white band that reaches the left border of the picture, the valley occupied by it being sunken below the level of the plateau so as to nearly conceal the glacier). The foreground is the gravel plain formed by streamlets issuing from the ice-cap. The snowy slope at the right is the wind-drift border lodged on the edge of the ice-cap. The terminal moraine is barely seen at the top of this, together with a belt of surface wash from a portion of the moraine not seen. In the background at the left is a more distant portion of the ice-cap. View taken looking westward.

valley glacier, viz., that there is little or no gathering together of water beneath the glacier.

The base of the ice-cap was reached at a height of about 2000 feet. It lay perhaps three miles back from the border of the gulf. No measurements of distance were made and this and similar statements in this article are only such rude approximations to the truth as may give a general impression of distances. It was not thought wise to consume precious time in measurements where accuracy had no importance.

The edge of the ice-cap was found to consist of a steep snowy slope rising to a height of about 100 feet, crowned by a terminal

moraine, beyond which rose the great dome of the ice-cap. Strangely enough here was a terminal moraine that was not terminal; a terminal moraine with an icy tract outside. This outer tract was in part fresh snow almost perfectly white, indicating that it was a wind-drift accumulation of recent date. At points, however, older discolored snow or ice appeared beneath it and in a few places stratified granular ice of glacial aspect and con-

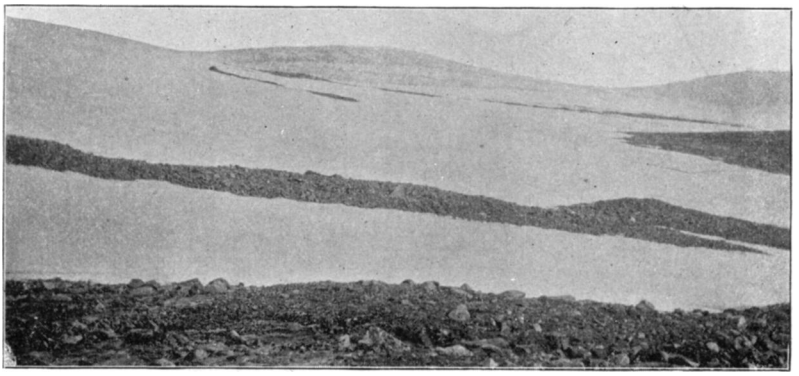

FIG. 41.—Southern edge of the ice-cap of Redcliff peninsula seen looking eastward from a point a short distance east of the Bryant glacier. The débris-strewn portion of the plateau forms the immediate foreground. Beyond this is the wind-drift belt of snow lodged outside the terminal moraine which lies just beyond it in the middle foreground. The dark lines of débris in the center of the picture are also parts of the terminal moraine which pursues a serpentine course controlled by the topography. The white portion in the center and at the left and the dome in the background are parts of the ice-cap.

taining some rocky material was seen. It was not clear, however, that this was not material that had rolled down the steep slope from the moraine above. The phenomenon was at first exceedingly puzzling, but subsequent study and the light which Lieutenant Peary threw upon the subject rendered the elucidation altogether clear. Lieutenant Peary (who had not yet been met) subsequently informed me that the winds of the ice-cap usually flow down its slope much as though they were independent and simply controlled by gravity. It is easy to see that the air in contact with the surface of the ice-cap becomes exceptionally cold.

The high specific gravity thus acquired is apparently sufficient to give it motion down the slope measurably independent of the general movement of the atmosphere, unless the latter is strong, hence the predominance of winds flowing down the slope of the ice-cap in lines normal to its border. By these snow is carried in large quantities over the moraine at the edge of the glacier and is lodged behind it. Thus arises an exceptional snow accumulation on the outer border of the moraine. This is so great in amount as to resist the limited melting of the summer and hence it persists from year to year and becomes solidified to a glacier-like consistency; indeed it may be regarded as a species of fringing glacier. Lieutenant Peary says that it is a prevalent phenomenon, not only around the borders of Inglefield Gulf but on the northeastern side of Greenland so far as reached by him in 1892. This wind-drift border varies in extent from a few rods to half a mile in breadth at the points where I saw it. Where first encountered on the plateau east of the Bryant glacier, it only reached a short distance in front of the terminal moraine. (Fig. 40.) A little to the east it was found to be considerably wider and in an adjacent depression to extend itself as a tongue a mile or so down the valley. Fig. 41 shows a portion of this wind-drift border of relatively flat surface and narrow breadth, as seen a short distance east of the Bryant glacier.

The acclivity of this border where I first encountered (Fig. 40) it was so steep as to make direct ascent difficult, but oblique ascent was found practicable, with a little care. On reaching its summit a sharply ridged moraine was found, the outer face of which was as steep as the material would lie. Indeed, some of the material appeared to have been dislodged and to have rolled down the snowy declivity. Just there the moraine only rose ten or twelve feet above its outer base, though elsewhere it appeared to reach a height of twenty or thirty feet. Beyond the sharp crest there was a descent of a few feet, and then an irregular surface a few rods in breadth. Inside this narrow and apparently shallow moraine and parallel to it, there ran a little brook fed by numerous streamlets from the ice-cap beyond. This brook ran along

between the moraine and the ice-cap for some distance to the eastward until it found a low point in the moraine, across which it flowed and became lost in the snowy slope fronting the moraine. It doubtless represents a mode of drainage of some prevalence during the glacial period. Beyond this infra-morainic brook the ice rose with a moderate slope up to the summit plane of the ice-cap.

On neither of my two visits to the ice-cap at this point did

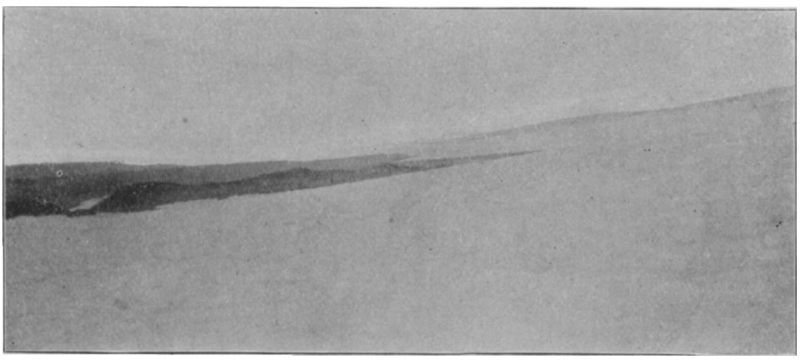

FIG. 42.—A portion of the Redcliff ice-cap seen from a point on the ice-cap looking westwardly, showing the terminal moraine at the left with a glimpse of the snow border beyond and the smooth summit lines of the plateau in the distance.

time permit any considerable ascent of its border. It was estimated to rise one or two thousand feet, and this accords with the estimate of Lieutenant Peary formed on better grounds. The surface of the ice-cap, except in the immediate vicinity of the frontal moraine, was found to be entirely free from débris, except atmospheric dust lodged upon it. No bowlders whatever were seen upon it. Crevasses were absent from the border of the ice-cap, so far as it was traversed, with the exception of mere cracks which did not appear to descend deeply, as they did not absorb the streamlets running over the surface. Dust wells and dirt holes were abundant, usually reaching six or eight inches in depth.

It will be observed that the terminal moraine lay between the wind-drift border and the ice-cap. We were very much struck

at first sight with the angularity of the contours of the moraine. It presented the appearance of having been pushed up from beneath. At some points there were sharp conical peaks that gave the impression of direct elevation from below. This appearance was afterwards supported by observations elsewhere and there seemed sufficient grounds for believing that the impression of the method of its formation was correct. It was found that the layers of the ice curved rapidly upward on encountering the wind-drift border and the moraine lodged against it, and that the morainic débris that resulted from its melting was borne on its upturned edge. Under these conditions any motion of the layers of the ice must have pushed upwards the material lodged upon their edges.

The material of the moraine was in general quite angular. There were occasional well rounded cobblestones and some well worn bowlders, while some other fragments were deangulated or rubbed and bruised, in a moderate measure, but notwithstanding these instances, the prevailing character was one of marked angularity. The material was chiefly light colored sandstone of the Karnah variety previously alluded to. Some crystalline bowlders were present. It would appear, therefore, either that the ice-cap was largely underlaid with Karnah sandstone, or else that the débris was chiefly picked up near its border, and of these alternatives the latter seemed best supported by the distribution of the formations and other considerations.

This moraine was seen to reach along the edge of the ice for some miles. To the east it could be seen pursuing a serpentine course along the ice front with a notable snow-drift belt outside. To the west it could be followed for a shorter distance beyond which its presence could not be detected, the ice-cap appearing to come down with a moderate slope to the surface of the plateau without any frontal moraine. But this tract was only seen from a distance and a moraine buried beneath a snow-drift border may have been present.

The ice front showed little evidence of motion. It appeared from the constitution of the wind-drift border that it was the

result of several years accumulations, but it did not appear to be disrupted or disturbed in any observable degree by pressure from the ice-cap beyond. The moraine, pushed up between the ice-cap and the snow-drift border, showed evidences of motion, as already indicated; but this must have been very slow, otherwise the moraine would have been pushed over the wind-drift border or both pressed forward together, of which there seemed to be no evidence. The material rolled along by the little fringing streams that bordered the ice-cap, was found to be rounded up to the very edge of the snow-drift border, and this strengthened the conviction that these little streams had been engaged in their work for some considerable period. Individually they were usually mere little shallow brooklets and the amount of erosion they could accomplish in a single year would be slight. The impression of slow motion and limited vigor was further strengthened by the fact that the water of these little streamlets was clear and free from observable silt. Had the ice been moving at any notable rate, or acting with any appreciable vigor on the angular sandstone at its edge and in its bottom, the issuing streams could scarcely have failed to be silty.

T. C. CHAMBERLIN.